Multi-scale, Interdisciplinary Investigation of CBM Development in the Powder River Basin of Wyoming

OBJECTIVES

The objectives of the project are to examine impacts of CBM development on the land surface, soils, plants, and energy and water resources of the PRB. The majority of the project's activities will occur within an area (roughly 200 km2) slated for a landscape change analysis. This area, to be selected in consultation with BLM, will be chosen to maximize opportunities for conducting investigations of current relevance to BLM science needs. It is certain that some project activities will occur outside of this area owing to site specific requirements of a particular investigation, needs for particular efforts to be conducted at a larger scale (perhaps basin-wide), and the possibility of new critical issues arising outside of the area. The project will incorporate some recently completed and ongoing USGS investigations related to CBM development. Examples of these investigations include studies of recharge and geochemical evolution of CBM production water being discharged into an ephemeral drainage (Burger Draw), ongoing monitoring of water quantity and quality in streams receiving CBM discharges, a gas resource evaluation and associated ground water quality investigation being conducted in cooperation with BLM, and an evaluation of invasive plant species distribution in CBM development areas. The project will attempt to build on these studies by using their findings and interpretations to pose new research questions. Special emphasis will be placed upon questions where capabilities from more than one discipline have the potential to lead to enhanced understanding. For example, it has been observed that CBM discharges into ephemeral channels result in year-round stream flow accompanied by rapid and dramatic increases in plant growth along the stream channel. A possible contributing factor in this change is dissolved nitrogen in the CBM discharge water. This nitrogen, which is discharged at the land surface as dissolved ammonium ion, undergoes significant chemical transformations as it is transported along the stream channel. Understanding the complex processes associated with this phenomenon will call upon expertise in plant ecology, hydrology, soil science, aquatic geochemistry and microbial ecology applied at the stream reach scale. Further, understanding the extent and cumulative impact of this landscape response could employ sampling across multiple watersheds as well as remote sensing techniques applied to larger land areas. The project team will attempt to address several such interdisciplinary questions during the course of the project. A key component of the project will be to compile, analyze, and present existing and newly acquired spatial data (soils, vegetation, geology, hydrology, topography, CBM infrastructure, etc.) within the study area.

PROBLEM

Development of coalbed methane (CBM) in the Powder River Basin (PRB) has increased at a near-exponential rate over the last decade. A recent Environmental Impact Statement (EIS), prepared by the Wyoming office of the Bureau of Land Management (BLM), addresses the possible operation of nearly 50,000 wells in the Wyoming portion of the PRB by 2010.Production of this resource from the PRB is a relatively new phenomenon, and the level of anticipated development there is unprecedented. Department of the Interior (DOI) land managers, especially those in BLM, are under significant pressure to accelerate development to meet current administration goals for increased domestic energy production. They must accomplish this while ensuring protection of air, land, biological, and water resources under their care. The scope of existing and anticipated CBM development in the PRB has generated a wide range of environmental concerns. These include the potential for contamination of ground and surface waters, detrimental changes in habitat, introduction of invasive species, depletion of ground-water resources, and cumulative impacts from the widespread, dispersed nature of the development. Most, if not all, of the issues of concern involve multiple scales, both aerial and temporal. For example, infrastructure (roads, power lines and pipelines) needed to establish and operate CBM wells can impact habitat of threatened or endangered species at the scale of a single well (<1 km2), and in aggregate, have impacts at the ecoregion scale (>10,000 km2). Similarly, ground water pumping and disposal associated with CBM production can impact local hydrologic flow systems near production wells and disposal points, whereas cumulative impacts of tens of thousands of production wells could perturb major regional hydrologic flow systems for hundreds of years. Integration of USGS interdisciplinary science capabilities across these various scales can provide science information that is directly relevant to BLM decision makers.

APPROACH

As our principal DOI partner, BLM will be actively engaged in project planning. The BLM, Buffalo Field Office (BFO) has primary responsibility for overseeing most of the CBM development with ties to federal lands and federal mineral rights in the Wyoming portion of the PRB. Recent activities in the PRB by all four USGS disciplines have established working relationships with BLM personnel (range managers, soil scientists, and hydrologists) from the BFO. As appropriate, BLM personnel from other offices (for example, the Wyoming State Office and National Science and Technology Center), and other DOI agency personnel will be kept informed of project plans and activities, and consulted on project directions. Funding from the Central Region Interdisciplinary Science Program (CRISP) was used to begin an interdisciplinary investigation of CBM water disposal practices at an infiltration reservoir (Skewed Reservoir) in fiscal year 2003.This project will continue to support activities at the Skewed Reservoir site as well as in an adjacent drainage (Burger Draw) that was the focus of a recently completed Director's Venture Capital project. USGS scientists will conduct site-specific, watershed-scale studies, as well as investigations covering larger areas, perhaps covering a large portion of the entire structural basin. Examples of anticipated investigations include quantification of recharge and vegetation changes resulting from surface disposal

of CBM discharges into ephemeral channels, quantification of solute transport into the shallow subsurface from a CBM infiltration reservoir, geochemical modeling of interactions between CBM discharge water and various geologic materials (soils, stream sediments, unsaturated zone minerals, etc.), analysis of nitrogen loading into perennial streams from surface discharge of CBM production water, landscape change analysis of areas undergoing rapid CBM development, and characterization of soils and other geologic materials to better understand interactions between CBM discharge waters and those materials. An attempt will be made to extrapolate findings from specific sites and watersheds to similar settings in larger areas of the PRB so that study results can be more broadly applied by decision makers. An already developed database platform, the Powder River Information Science Access Site (PRISAS) will be used to serve spatial data, provide decision support tools, and provide web page information about the project.

RELEVANCE

One benefit will be increased scientific understanding of environmental impacts of a relatively new, and increasingly prevalent, method of energy production. An interdisciplinary team of USGS scientists, integrating the agency's unique capabilities, should be able to develop a more complete view of the complex, interrelated impacts of CBM development on the energy, biologic and hydrologic resources of the PRB. An equally important benefit will be the development of data and interpretations that will have relevance for BLM land managers coping with the unprecedented pace and scope of CBM development in the PRB. Products and data from this project will also be of interest to current USGS customers such as the Wyoming Department of Environmental Quality, Wyoming State Engineer's Office, USEPA, USFWS, and to CBM producers, advocacy groups and private citizens. Because a portion of the CBM development in the PRB is occurring on and near public lands, environmentally sound CBM production is of benefit to all U.S. citizens. The Director's goals for integrated science will be advanced as the work at the site will provide opportunities for USGS scientists from all disciplines to work jointly within a common study area on scientific problems related to CBM development, an activity that is of significant interest to other DOI agencies.

TASK 1

PROBLEM

Coalbed methane (CBM) development in the Powder River Basin (PRB) has proceeded at an unprecedented pace in the last 5 years. However, the scientific data and understanding needed to develop CBM in an ecologically sound manner has not kept pace. Objective scientific data and interpretations on the effects of water co-produced with CBM and on the effects of infrastructure development associated with CBM are particularly needed and desired. The Bureau of Land Management (BLM) and State agencies are charged with overseeing CBM development in a sound manner, but lack the resources, time, and/or expertise to investigate the associated science issues.

In order to produce CBM, the coal beds must be dewatered to relieve the pressure in the reservoir. The water is brought to the surface and must then be managed in an ecologically and economically sound manner. The volumes of water associated with CBM in the PRB are relatively large (over 150 barrels/day/well) because the coal beds of the Wyodak-Anderson coal zone function as regional aquifers in the PRB.

Many of the most pressing scientific questions concern various water management strategies in the PRB. Questions include: will the water infiltrate, where does it go if it does infiltrate, how fast does the water infiltrate, how does the chemical quality of the CBM water change as it interacts with soil and sediment, how far does water infiltrate in channel environments, where do the soluble salts in the soils and CBM water go, and how do soil and sediment properties change after application of CBM water and can these changes be ameliorated after CBM development. The answers to these questions lie in detailed study of the water and solid phases in each scenario and the interactions between them.

OBJECTIVES

The objectives of Task 1 are to study the effects of CBM development in areas of the PRB targeted for the next major phases of development. The task will study the disposal or reuse of water co-produced with CBM in typical water management scenarios including discharge to infiltration impoundments, discharge to drainages, and/or land application. The CBM water management strategies will affect local hydrology, both surface and subsurface, including water tables, flow paths, and water quality. Characterizing and understanding the effects involves determining infiltration rates, flow paths, and water quality changes as well as relating these to the local geology, mineralogy, and soil structure.

The focus of Task 1 will initially be at Skewed Reservoir, a CBM water infiltration impoundment on BLM surface land that is operated by Anadarko Petroleum. Skewed Reservoir is located in the Powder River Breaks area of the PRB about midway between Gillette and Buffalo, WY and just south of Interstate 90. The site is within 1/2 mile of Beaver Creek which drains into the nearby Powder River. The next major phase of CBM

development is in the Breaks area targeting the Big George coal bed. Funds from the Central Region Integrated Science Project were used in FY03 to begin studying water infiltration at Skewed Reservoir and this effort will now be expanded and continued.

Scientists will collect and analyze data from monitoring wells, lysimeters, core, and soil profiles and grabs in and near Skewed Reservoir. This data will be used to determine CBM water infiltration rates over time, changes in CBM water quality during infiltration, changes to local hydrogeology, movement and fate of soluble salts in shallow soils, and changes to the water, soil and regolith from reactions between CBM water and the solid medium. The data and analysis will be accomplished so that the underlying processes controlling the observed changes can be documented and understood so that results may be applied to other water disposal sites in the PRB.

FY '04 PLANS

1. Continue collection of water samples from monitoring wells and lysimeters at Skewed Reservoir in the PRB. Samples will be collected on a monthly basis if possible.

2. Analyze water samples from monitoring wells and lysimeters and compile and interpret results from same.

3. Collect water level data from monitoring wells and construct a detailed elevation map for Skewed Reservoir that will allow water level data to be interpreted.

4. Process core samples from FY03 drilling at Skewed Reservoir to determine physical and chemical properties including hydraulic conductivity, mineralogy, particle size, exchange properties, bulk chemistry, and soluble phases.

5. Conduct leaching tests with Skewed Reservoir core material and selected eluants such as deionized water and CBM water.

6. Select additional core and monitoring well sites at Skewed Reservoir based on preliminary results and conduct drilling to install wells or gather core as needed.

7. Collect additional soil samples at selected sites where Biology Discipline Researchers are conducting Forest Inventory Analysis plots to look at plant cover and diversity.

8. In coordination with BLM, pursue the selection and initial setup of an additional site to study effects of CBM development.

SUB-TASK 1.1

FYO4 PLANS

Continue collection of water samples from monitoring wells and lysimeters at Skewed Reservoir in the PRB. Samples will be collected on a monthly basis if possible.

Collect water level data from monitoring wells and construct a detailed elevation map for Skewed Reservoir that will allow water level data to be interpreted.

Select additional core and monitoring well sites at Skewed Reservoir based on preliminary results and conduct drilling to install wells or gather core as needed.

In coordination with BLM, pursue the selection and initial setup of an additional site to study effects of CBM development.

SUB-TASK 1.2

FYO4 PLANS

Continue collection of water samples from monitoring wells and lysimeters at Skewed Reservoir in the PRB. Samples will be collected on a monthly basis if possible.

Analyze water samples from monitoring wells and lysimeters and compile and interpret results from same.

Process core samples from FY03 drilling at Skewed Reservoir to determine physical and chemical properties including hydraulic conductivity, mineralogy, particle size, exchange properties, bulk chemistry, and soluble phases.

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In coordination with BLM, pursue the selection and initial setup of an additional site to study effects of CBM development.

SUB-TASK 1.3

FY04 PLANS

1. Continue collection of water samples from monitoring wells and lysimeters at Skewed Reservoir in the PRB. Samples will be collected on a monthly basis if possible.

2. Analyze water samples from monitoring wells and lysimeters and compile and interpret results from same.

Process core samples from FY03 drilling at Skewed Reservoir to determine physical and chemical properties including hydraulic conductivity, mineralogy, particle size, exchange properties, bulk chemistry, and soluble phases.

Conduct leaching tests with Skewed Reservoir core material and selected eluants such as deionized water and CBM water.

Select additional core and monitoring well sites at Skewed Reservoir based on preliminary results and conduct drilling to install wells or gather core as needed.

Collect additional soil samples at selected sites where Biology Discipline Researchers are conducting Forest Inventory Analysis plots to look at plant cover and diversity.

In coordination with BLM, pursue the selection and initial setup of an additional site to study effects of CBM development.

TASK 2

PROBLEM

Development of coalbed methane (CBM) in the Powder River Basin (PRB) has increased at a near-exponential rate over the last decade. A recent Environmental Impact Statement (EIS), prepared by the Wyoming office of the Bureau of Land Management (BLM), addresses the possible operation of nearly 50,000 wells in the Wyoming portion of the PRB by 2010. Production of this resource from the PRB is a relatively new phenomenon, and the level of anticipated development there is unprecedented. Department of the Interior (DOI) land managers, especially those in BLM, are under significant pressure to accelerate development to meet current administration goals for increased domestic energy production. They must accomplish this while ensuring protection of air, land, biological, and water resources under their care. The scope of existing and anticipated CBM development in the PRB has generated a wide range of environmental concerns. These include the potential for contamination of ground and surface waters, detrimental changes in habitat, introduction of invasive species, depletion of ground-water resources, and cumulative impacts from the widespread, dispersed nature of the development. Most, if not all, of the issues of concern involve multiple scales, both aerial and temporal. For example, infrastructure (roads, power lines and pipelines) needed to establish and operate CBM wells can impact habitat of threatened or endangered species at the scale of a single well (<1 km2), and in aggregate, have impacts at the ecoregion scale (>10,000 km2). Integration of USGS interdisciplinary science capabilities across these various scales can provide science information that is directly relevant to BLM decision makers.

OBJECTIVES

The objectives of the project are to examine impacts of CBM development on the land surface, soils, plants, and energy and water resources of the PRB. This task addresses the "plants" component of the project objective and will contribute data (e.g., soils) directly to the other components.

METHODOLOGY

We will stratify the study area based on features of interest such as: pads, pipelines, discharge areas, holding ponds and road types (traffic volume, surface condition, etc.).

Multi-scale plots customized for feature size will be placed randomly within strata to provide at least three plots per stratum. Within the plots we record vegetation cover by species in the 1 square meter subplots. Within the other subplots and the entire plot we record all species. Where present, we will record the cover of algal mats (related to surface water discharge) and biological soil crusts by development class in the 1 square meter subplots. All field data will be directly entered into MS Access using the data-entry interface and database structure developed by Stohlgren et al. (free software for Palms).
At each vegetation sampling plot we will take repeatable digital photography from the plot origin to the opposite corner and at three of the 1 square meter subplots. We will take additional photos where extensive biological soil crusts, non-native species, algal mats, or other interesting components are present. Digital photos will be managed within the MS Access database. For an example of photopoint application see: http://www.fort.usgs.gov/products/data/photopts/

FYO4 PLANS

Sample vegetation in conjunction with the interdisciplinary team. Manage the vegetation plot data and digital photographs in MS Access. Provide data to other investigators on this project as needed. Present results in multiple formats to BLM, USGS, and other outlets as appropriate.

TASK 3

PROBLEM

Activities related to coalbed methane exploration and development – construction of access roads, well pads, pipelines, utility corridors, compressor stations, and water reservoirs – create changes on the landscape. Information on the types and extent of change occurring in the PRB in the time pre-CBM development to post-CBM development would be beneficial to land managers who are trying to determine where change may occur, and the types and amounts of change that may be acceptable. A cursory literature review found no research that is attempting to qualify and quantify landscape change in the PRB.

OBJECTIVES

Compile and develop data for temporal land cover inventories, and temporal and spatial analyses for an area in the PRB (exact area and location to be determined). Examples of such analyses may include a change detection, study of land cover change with distance from well pads, and fragmentation statistics.

FY04 PLANS

The focus of this task in Year One (FY04) will be acquiring the appropriate imagery to be used in the land cover classifications and future analyses. Minimally, 1994 and 2001

DOQQs will be acquired for this purpose. Optimally, a third time slice will be added using 2004 Quickbird satellite data. As time allows, the land cover classifications will begin.

TASK 4

PROBLEM

The relevance of DOI and USGS science related to CBM will rely on our ability to use geospatial information and web mapping services to relate, integrate, distribute and share scientific information.
The Multi-scale, Inter-disciplinary CBM Development project has adopted the existing Powder River Information Science Access Site or PRISAS as a means to provide a resource to share this science among USGS disciplines, the Department and other partners and supports internal as well as external cooperative science.

OBJECTIVES

PRISAS will meet the requirements outlined in the DOI Science on the Landscape initiative by:
1 Establishing an organized database
2 Working with GIO to provide involvement and support in developing integrated science database support
3 Providing associated standard metedata for each data layer produced or served
4 Providing spatial data in standard ARC/INFO format
5 Developing a database platform to maintain and serve data for use by USGS and Bureau partners
6 Contributing content for a web page that will be created for each project.
7 Providing pertinent geospatial data to The National Map

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TASK 5

PROBLEM

Redox reactions are the fundamental energy-generating processes for all living things. Microorganisms are particularly versatile in their ability to catalyze redox reactions and can grow on a wide range of redox couples (i.e. different oxidants and reductants). For this reason, microbes are often important mediators of biogeochemical change, especially when reduced waters enter oxidized environments, or vice versa. Microbes establish themselves at such boundaries and significantly enhance the alterations that occur in the chemistry of the water.

Water obtained from subsurface, saturated coal beds typically contains many kinds of reduced chemical constituents. These can include, besides methane, hydrogen, ferrous iron, hydrogen sulfide, ammonium, and high concentrations of particulate and dissolved organic carbon. When this water is pumped for recovery of methane and then discharged on the land surface, it is abruptly subjected to an oxidizing environment, entraining molecular oxygen from the atmosphere. The simultaneous presence of oxygen and the multitude of reductants from the subsurface is a kind of disequilibrium paradise for many types of microbes. A variety of microbially-mediated redox reactions will be established in such an environment. The net effect of these processes will be a substantial alteration in the chemical composition of the water at locations down-gradient in the flow path.

This project will specifically examine the fate of ammonium present in coal bed methane discharge waters. As a source of fixed nitrogen, ammonium has the potential to eutrophy the receiving watershed. The extent to which this happens depends on the combination of biogeochemical processes that act upon ammonium. These include nitrification, denitrification, and uptake by plants and algal biomass. Because the hydrologic regime also provides an important feedback on these processes and their interaction with the environment, the type of water disposal practice may have significant differences in the down-gradient impact of the CBM nitrogen. Thus, the project will compare and contrast specific nitrogen cycling processes and the effect on nitrogen loads in an open stream channel discharge of CBM water vs. impoundment and infiltration.

OBJECTIVES

The purpose of this study will be to document the changes in dissolved inorganic nitrogen (DIN) composition of discharged coal bed methane (CBM) water along selected flow paths and to quantify and characterize the biogeochemical process(es) responsible for the predominant changes. The study will examine whether there are significant differences in the processes and the net nitrogen loads in 2 different types of water management practices; open channel discharge vs. discharge into an impoundment designed for infiltration. The processes that occur along each flow path will need to be considered within the relevant biological, hydrological and geochemical contexts of each environment.

METHODOLOGY

This portion of the study will be conducted in Burger Draw, an open channel discharge site, and Skewed Reservoir, an infiltration impoundment site. Both are located in Johnson County, Wyoming. The approach will be to document dissolved inorganic nitrogen (DIN) speciation and concentration with transport at each of the two study sites and then measure the rates of key nitrogen-cycling processes occurring within each environment.

1) General Survey of Water Chemistry. Water samples will be collected along selected flow paths and analyzed for a variety of constituents. Sampling will be in a synoptic fashion along selected reaches and at fixed stations on a diel basis. Analyses will include, field physical parameters (pH, temperature, specific conductance), inorganic anions and cations (with attention to all DIN species), dissolved and particulate organic carbon, dissolved gases (oxygen, carbon dioxide, methane, hydrogen, nitrous oxide), metals, total dissolved nitrogen, and direct counts of microbial biomass. Sampling events will occur at different time of the year and will be correlated with weather, incident light, and plant cover.

2) Assessment of Biogeochemical Processes. The water chemistry data will indicate what biogeochemical processes are likely to be most active within the stream bed and the unsaturated zone. It will not, however, provide a direct demonstration that the processes are occurring, the extent to which these processes are occurring, nor the factors that control the processes. These assessments will be done using activity assays. The specific assays will vary, depending upon the processes that appear to be significant in the system and thus would warrant further examination. But the general approach will be the same. Denitrification and nitrification will be specifically examined in these studies.

A) Laboratory incubations. The first step will be to conduct activity assays in a laboratory under controlled conditions. These types of incubations can test directly whether a given sediment or water sample has the capacity to carry out a particular process and to what extent. Laboratory incubations can also be used to test a variety of factors that might affect the rate at which a reaction is occurring. It is likely that samples will be collected on several occasions for the laboratory incubations.

B) In situ tracer incubations. To the extent possible, the more significant biogeochemical processes will be assessed in the field using in-stream incubation chambers and tracer tests. Both approaches allow quantification and assessment of a process within the context of the in situ geochemistry. Changes in concentration or chemical composition of the water and the individual tracers provide quantification of the process of interest. In the case of the in-stream tracer tests, the processes are quantified within the hydrologic regime. For stream channel flow paths, the tests would be conducted over short reaches of the stream. All of the tracer tests would require intense activity of 5 or 6 people for up to a 3-day period. As they usually generate large numbers of samples, any given tracer test would only be conducted once or twice.

FY04 PLANS

1) Detailed synoptic and diel sampling will be conducted in Burger Draw, focusing on the main channel and Tributary 2. Samples will be collected for 4-5 day intervals and correlated with incident light and temperature. Several sampling stations will be deployed along Tributary 2.
2) A rhodamine tracer test will be conducted in Tributary 2 to determine time of travel and hyporheic exchange.
3) Preliminary synoptic sampling will be conducted in Skewed Reservoir. This will be in conjunction with at least one lysimeter sample collection event that will take place in Task #1. The focus will be on changes in DIN concentrations relative to reservoir residence time.
4) Conduct in-stream incubation in Burger Draw using small-scale incubation containers. These will focus on Tributary 2 and diel changes in potential activities.
5) Conduct laboratory incubation with Burger Draw sediment and water to characterize potential denitrification and nitrification activity. Experiments will be conducted to evaluate geochemical controls on these two processes.